A Simple Theory of Offshoring and Reshoring

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Abstract

In this study, we predict a pattern of offshoring and reshoring over the course of economic development. We assume that offshoring requires both workers and capital in the offshored country. Hence, the accumulation of capital in the offshored country has two opposing effects on offshoring. On the one hand, it decreases the rental price of capital rendering offshoring more attractive. On the other hand, it increases the wage rate of workers rendering offshoring less attractive. Putting these two effects together, we analytically generate an offshoring Kuznets curve (i.e., an inverted-U pattern of offshoring), consistent with what observed in China.

JEL classification: F11, F16
Keywords: trade, offshoring, economic development

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"A growing number of American companies are moving their manufacturing back to the United States." The Economist (2013)

1 Introduction

From the mid 1990's to the late 2000's, the amount of offshoring from developed countries to China steadily increased. Xing (2012) documents that the volume of processing trade in China increased from about US$10 billion in 1994 to US$300 billion in 2008. However, this increasing trend of offshoring in China started to reverse in the early 2010's.[1] Figure 1 presents the time trend of manufacturing imports as a share of GDP in China. The figure shows that even before the recent trade dispute between China and the US, some manufacturing activities already started to shift away from China. In this study, we show how a simple model of offshoring can explain this pattern of offshoring and reshoring.

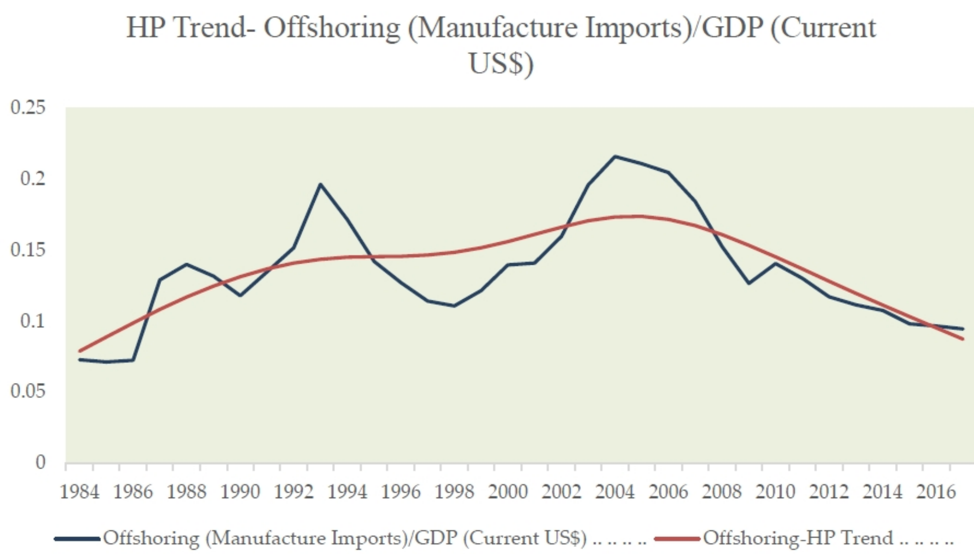

Figure 1

This emerging pattern of reshoring is due to the rising production cost in China. The Boston Consulting Group (2012b) finds that the "15 to 20 percent annual increases in Chinese wages [...] were rapidly eroding China's manufacturing cost advantage over the U.S.". Porter

[1] According to the Boston Consulting Group (2011), "[t]ransportation goods such as vehicles and auto parts, electrical equipment including household appliances, and furniture are among seven sectors that could create 2 to 3 million jobs as a result of manufacturing returning to the U.S. - an emerging trend that is expected to accelerate starting in the next five years". In a subsequent survey, the Boston Consulting Group (2012a) finds that "[m]ore than a third of U.S.-based manufacturing executives at companies with sales greater than $1 billion are planning to bring back production to the United States from China or are considering it". For example, in April 2012, GE announced a $1 billion investment in the business of domestic appliances with the objective of reshoring manufacturing tasks from plants in China and Mexico to plants in the US; see Financial Times (2012).

and Rivkin (2012) also argue that rapidly rising wages abroad represent an important trend that is beginning to make US firms favor locating their production domestically. Yang et al. (2010) document the time series of real wages in China and find that the average real wages more than tripled from 1997 to 2007. Figure 2 presents the time trend of average wages in China.

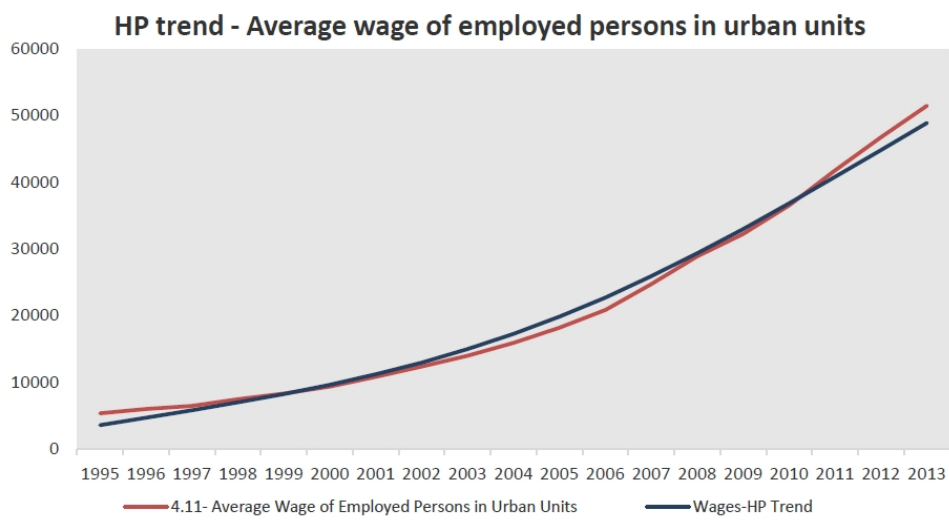

Figure 2

Another important stylized fact of economic development in China is that physical capital has been accumulating at a rapid rate in China. According to Bai et al. (2006), gross fixed capital formation as a share of gross domestic product in China increased from 30% in 1978 to 42% in 2005. Figure 3 presents the time trend of the stock of capital in China.

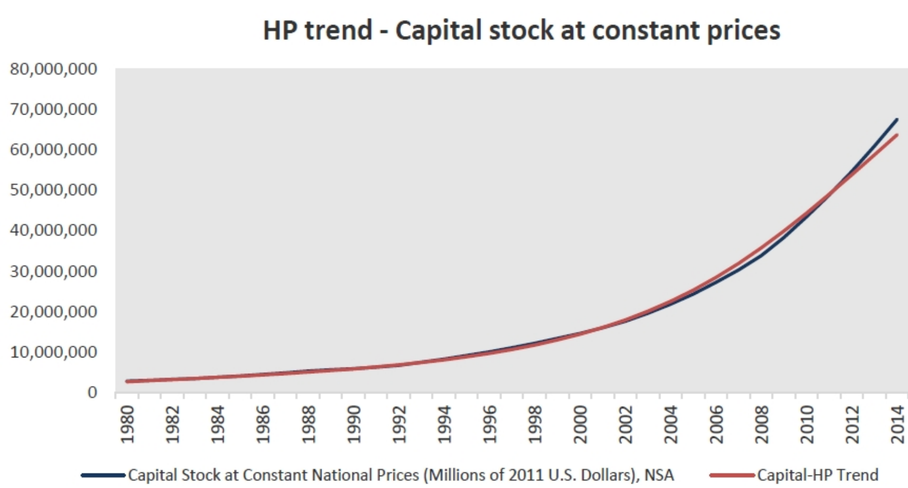

Figure 3

At the first glance, capital accumulation in China should lead to a gradual reduction in offshoring because of its positive effect on wages, which renders offshoring less attractive. However, if one considers an often neglected fact that offshoring also requires the use of domestic capital in the offshored country (i.e., offshored production requires both workers and equipment in the offshored country), then capital accumulation in China would also have a positive effect on offshoring.

To generate the abovementioned patterns, it suffices to consider the seminal model of offshoring in Grossman and Rossi-Hansberg (2008).[2] We extend the Grossman-Rossi-Hansberg model by allowing for the possibility that offshoring of labor-intensive tasks requires the use of both workers and capital (e.g., plants, equipment, information and telecommunication structures[3]) in the offshored country. In this case, an increase in the capital stock in China has two opposing effects on the incentives of offshoring. On the one hand, it increases the wage rate of workers rendering offshoring less attractive. On the other hand, it decreases the rental price of capital rendering offshoring more attractive. According to Bai *et al.* (2006), the rate of return to non-mining capital in China decreases from 30% in the mid 1980's to less than 20% in the early 2000's. Putting these two effects together generates an inverted-U effect of capital accumulation on the equilibrium level of offshoring, which gives rise to an inverted-U pattern of offshoring over the course of economic development.[4] We refer to this pattern as an offshoring Kuznets curve, which has been observed in China. However, our prediction does not apply only to the albeit very important Chinese case, but also to the generality of other offshored countries.

2 A simple model of offshoring and reshoring

We consider the Grossman-Rossi-Hansberg model of offshoring. The model consists of two goods $j \in \{x, y\}$, which are produced using labor and capital in the form of two varieties of tasks: L-tasks and K-tasks. The measure of each variety of tasks is normalized to one. Firms in the developed country produce both goods. In addition to employing local workers, they can also offshore some of the L-tasks to workers in the developing country. Here we differ from Grossman and Rossi-Hansberg (2008) by assuming that this offshoring process also requires the use of capital in the developing country in order to capture a simple fact that workers in China require local equipment to complete the offshored tasks. Therefore, both capital and labor in the developing country can either be used for domestic production or for offshoring production.

We will refer to the developing country (for example, China) as the home country. To illustrate our story, it suffices to consider a simple case of the Grossman-Rossi-Hansberg

[2] In the literature on offshoring, there is an important alternative strand of studies that focus on the choice of organizational form by firms; see the seminal studies by McLaren (2000), Grossman and Helpman (2002, 2004, 2005), Antras (2003), Antras and Helpman (2004) and Antras *et al.* (2006).

[3] Communication between the offshored country and the offshoring country is essential for the offshoring activity, which requires telephones, faxes, and computers, etc.

[4] Krenz, Prettner, and Strulik (2018) develop a complementary model able to generate a similar pattern of offshoring and reshoring in a richer environment also featuring R&D and automation.

model by assuming that the home country is a small open economy.[5] In order for the effects of factor supplies to work explicitly, as is well known in international trade theory, we also need more factors than produced goods;[6] therefore, we assume that the home country produces only one good, say good y. In this industry, a firm needs a_{fy} units of domestic factor $f \in \{L, K\}$ to perform a typical f-task. Due to substitutability between L-tasks and K-tasks, firms choose a_{Ly} and a_{Ky} to minimize their cost. Following Grossman and Rossi-Hansberg (2008), we assume that there is no substitution within the f-tasks, so that each task must be performed once to produce a unit of good y.

If a foreign firm in industry j performs L-task i using local workers, it requires a^*_{Lj} units of local labor. If the foreign firm performs L-task i through offshoring, it requires $l_j(i) = a^*_{Lj}\beta t(i)$ units of labor and $k_j(i) = \delta l_j(i)$ units of capital in the offshored country. We assume that the offshored tasks require the use of capital for the offshoring process. The parameter $\beta > 0$ is a shift parameter that inversely captures technological improvement in offshoring, and the parameter $\delta \geq 0$ measures the extent to which each offshoring worker requires local capital (e.g., the equipment that each worker needs to perform the tasks). $t(i)$ is a continuous function, and the tasks are ordered by increasing difficulty of offshoring (i.e., $t'(i) > 0$ for $i \in [0, 1]$).

Due to the assumption of the home country being a small open economy, all foreign variables denoted by superscript * are given exogenously. Naturally, we focus on the equilibrium in which offshoring exists by imposing the following parameter restrictions:

$$w^* > \beta t(0)(w + \delta r), \tag{P1}$$
$$w^* < \beta t(1)(w + \delta r). \tag{P2}$$

Given (P1) and (P2), there must exist a threshold value denoted as $I \in (0, 1)$, such that

$$w^* = \beta t(I)(w + \delta r). \tag{1}$$

The left-hand side of (1) is the wage cost for firms in the foreign country whereas the right-hand side is the offshoring costs of task I. In both industries $j \in \{x, y\}$, for $i \leq I$, foreign L-tasks are offshored to the home country. For $i > I$, foreign L-tasks are performed domestically in the foreign country.

In the home country, the unit cost for domestic firms in industry y is $wa_{Ly} + ra_{Ky}$. Perfect competition implies

$$wa_{Ly} + ra_{Ky} = p_y = 1, \tag{2}$$

where we normalize the world price of good y to $p_y = 1$. The factor-market condition for labor in the home country is given by

$$a_{Ly}y + Z^*\beta \int_0^I t(i)di = L, \tag{3a}$$

[5] In an online appendix (see Appendix B), we consider a two-country version of the model and show that capital has an inverted-U effect on offshoring if and only if the elasticity of substitution between x and y is greater than unity.

[6] Given this assumption, factor price equalization does not hold. Although capital may be mobile across countries in reality, there is capital control that leads to imperfect capital mobility in China, so the rental prices of capital in China and abroad should not be equalized.

where $Z^* \equiv a^*_{Lx}x^* + a^*_{Ly}y^*$ captures the production scale in the foreign economy. In other words, labor in the home country is either used for domestic production $a_{Ly}y$ or offshoring production $Z^*\beta \int_0^I t(i)di$ for foreign firms. Similarly, the factor-market condition for capital in the home country is given by

$$a_{Ky}y + Z^*\delta\beta \int_0^I t(i)di = K. \tag{3b}$$

In other words, capital in the home country is either used for domestic production $a_{Ky}y$ or offshoring production $\delta\beta Z^* \int_0^I t(i)di$ for foreign firms.[7]

From cost minimization, we can derive $a_{fy}(w/r)$ as a function of w/r, where w is the wage rate of workers and r is the rental price of capital. Taking $a_{fy}(w/r)$ into account, the equilibrium conditions (1), (2) and (3) determine $\{w, r, y, I\}$. Using (3), we can express capital intensity in the home country as

$$\frac{a_{Ky}}{a_{Ly}} = \frac{K - \delta\beta Z^* \int_0^I t(i)di}{L - \beta Z^* \int_0^I t(i)di}. \tag{4}$$

Given that a_{Ky}/a_{Ly} is naturally an increasing function of w/r,[8] the ratio w/r can be expressed using (4) as

$$\frac{w}{r} \equiv \omega(I; K). \tag{5}$$

By (4), we may note two properties of the function ω: (a) ω is increasing (decreasing) in I if $K > (<)\ \delta L$; and (b) ω is increasing in K. We now solve (2) and (5) for r and w to obtain the expressions of $w(\omega(I;K))$[9] and $r(\omega(I;K))$[10], where $w'(\cdot) > 0$ and $r'(\cdot) < 0$.[11]

We substitute $w(\omega(I;K))$ and $r(\omega(I;K))$ into (1) to obtain

$$w^* = \beta t(I)[w(\omega(I;K)) + \delta r(\omega(I;K))], \tag{6}$$

which determines the equilibrium level of offshoring I for a given K. The offshoring costs in the right-hand side of (6) may increase or decrease with $\omega(I;K)$, and the following chart summarizes the intuition.

$$K\uparrow \Rightarrow \omega(I;K)\uparrow \Rightarrow \begin{array}{c} r\downarrow \Rightarrow \text{offshoring cost}\downarrow \\ w\uparrow \Rightarrow \text{offshoring cost}\uparrow \end{array} \Rightarrow I \uparrow\downarrow .$$

As K increases, the capital cost r decreases but the wage cost w increases. To understand how these effects affect offshoring, we consider a CES technology with the following unit production function $\left[\theta\left(a_{Ky}\right)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\theta)\left(a_{Ly}\right)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}} = 1$, where $\varepsilon > 0$ is the elasticity of

[7] To ensure a positive output of y, we assume $L > \beta Z^* \int_0^I t(i)di$ and $K > \delta\beta Z^* \int_0^I t(i)di$.

[8] We will consider an explicit production function below.

[9] Specifically, $w(\omega(I;K)) = \omega(I;K)/[\omega(I;K)a_{Ly}(\omega(I;K)) + a_{Ky}(\omega(I;K))]$.

[10] Specifically, $r(\omega(I;K)) = 1/[\omega(I;K)a_{Ly}(\omega(I;K)) + a_{Ky}(\omega(I;K))]$.

[11] In Appendix A, we derive these comparative statics.

substitution between capital and labor. Cost minimization implies that the factor price ratio in (5) becomes

$$\omega(I;K) = \frac{1-\theta}{\theta}\left(\frac{a_{Ky}}{a_{Ly}}\right)^{\frac{1}{\varepsilon}} = \frac{1-\theta}{\theta}\left(\frac{K-\delta\ \beta Z^{*}\int_0^I t(i)di}{L-\beta Z^{*}\int_0^I t(i)di}\right)^{\frac{1}{\varepsilon}}. \tag{7}$$

Finally, using (7) and the unit production function, we can express (6) as[12]

$$w^{*} = \beta t(I)\left\{\underbrace{\left[\theta^{\varepsilon}\omega\left(I;K\right)^{\varepsilon-1}+(1-\theta)^{\varepsilon}\right]^{\frac{1}{\varepsilon-1}}}_{w(\omega(I;K))}+\delta\underbrace{\left[\theta^{\varepsilon}+(1-\theta)^{\varepsilon}\omega\left(I;K\right)^{-(\varepsilon-1)}\right]^{\frac{1}{\varepsilon-1}}}_{r(\omega(I;K))}\right\}. \tag{8}$$

We first consider the special case of $\delta = 0$ as in Grossman and Rossi-Hansberg (2008). In this case, a larger stock of capital increases the wage rate of workers rendering offshoring less attractive; in other words, capital has a monotonically negative effect on offshoring I, which is inconsistent with empirical observation. When $\delta > 0$, the negative effect of capital on the rental price r generates an additional positive effect on offshoring. Putting these two effects together generates an inverted-U relationship between offshoring and capital, which is consistent with the recently observed inverted-U pattern of offshoring in China. We summarize all these effects in the following proposition.

Proposition 1 *As capital K increases in the offshored country, the wage rate w increases and the rental price r of capital decreases. As for the equilibrium level of offshoring I, it first increases and then decreases after K exceeds δL. In other words, there is an inverted-U relationship between offshoring I and the capital stock K in the offshored country.*

Proof. Differentiating the right-hand side of (8) with respect to I, we can show that it is monotonically increasing in I, noting (7).[13] Given that the left-hand side of (8) is constant and that a single crossing of the two sides of (8) is guaranteed by (P1), (P2) and the continuity of $t(i)$, there uniquely exists an equilibrium level of I that is determined by the intersect of both sides. Differentiating the right-hand side of (8) with respect to K, we can show that it is decreasing (increasing) in K when $K < (>)\delta L$, noting (7).[14] Finally, a simple graphical analysis would suffice to complete the proof. ■

3 Conclusion

In this study, we first summarized a phenomenon of offshoring and reshoring in China. Then, we developed a simple framework to explain this changing pattern on the location of

[12] In Appendix A, we provide the derivations.
[13] In Appendix A, we provide the derivations.
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manufacturing tasks. In summary, we find that economic development in offshored countries initially causes an increase in offshoring activities but eventually leads to a return of offshoring tasks to developed countries. Intuitively, capital accumulation as a result of economic development in offshored countries raises the wage rate of workers and reduces the rental price of capital giving rise to a U-shaped pattern in the cost of offshoring over the course of economic development, which in turn leads to an inverted-U pattern of offshoring. We refer to this pattern as an offshoring Kuznets curve.

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Appendix A

Comparative statics of $r(\cdot)$ and $w(\cdot)$:

Assume that the unit production function $F(a_{Ky}, a_{Ly})$ satisfies the standard neoclassical properties: for each $i = K,\ L,\ \partial F(a_{Ky}, a_{Ly})/\partial a_{iy} = F_i(a_{Ky}, a_{Ly}) > 0$; $\partial^2 F(a_{Ky}, a_{Ly})/\partial(a_{iy})^2 = F_{ii}(a_{Ky}, a_{Ly}) < 0$; $\lambda F(a_{Ky}, a_{Ly}) = F(\lambda a_{Ky}, \lambda a_{Ly})$ for any $\lambda > 0$. First, given the homogeneity of degree 1 in function $F(a_{Ky}, a_{Ly})$, we can have

$$r = F_1(a_{Ky}, a_{Ly}) \text{ and } w = F_2(a_{Ky}, a_{Ly}), \tag{A1}$$

noting $p_y = 1$. We can easily verify from Euler's homogeneous function theorem that $F_i(a_{Ky}, a_{Ly})$ is homogeneous of degree 0 for each i, implying $F_1(a_{Ky}, a_{Ly}) = F_1(a_{Ky}/a_{Ly}, 1)$ and $F_2(a_{Ky}, a_{Ly}) = F_2(a_{Ky}/a_{Ly}, 1)$. Given these two expressions, with $F_{ii}(a_{Ky}, a_{Ly}) < 0$, $F_1(a_{Ky}, a_{Ly})$ is a decreasing function in a_{Ky}/a_{Ly}. Since $\partial^2 F(a_{Ky}, a_{Ly})/(\partial(a_{Ky})\partial(a_{Ly})) = F_{21}(a_{Ky}, a_{Ly}) > 0$ holds due to the neoclassical properties, $F_2(a_{Ky}, a_{Ly}) = F_2(a_{Ky}/a_{Ly}, 1)$ is an increasing function in a_{Ky}/a_{Ly}. By the cost minimizing condition $F_2(a_{Ky}, a_{Ly})/F_1(a_{Ky}, a_{Ly}) = w/r$, we then verify a positive relationship between a_{Ky}/a_{Ly} and w/r. As a result, $F_1(a_{Ky}, a_{Ly})$ ($F_2(a_{Ky}, a_{Ly})$) is a decreasing (increasing) function in w/r. Equation (A1) ensures that r (w) increases (decreases) with w/r.

Derivations of equation (8):

The cost minimization condition gives rise to

$$\frac{a_{Ky}}{a_{Ly}} = \left(\frac{\theta}{1-\theta}\frac{w}{r}\right)^{\varepsilon}. \tag{A2}$$

By (A1) and (A2),

$$r = \left(\theta^{\varepsilon} + (1-\theta)^{\varepsilon}\left(\frac{w}{r}\right)^{-(\varepsilon-1)}\right)^{\frac{1}{\varepsilon-1}} \text{ and } w = \left(\theta^{\varepsilon}\left(\frac{w}{r}\right)^{\varepsilon-1} + (1-\theta)^{\varepsilon}\right)^{\frac{1}{\varepsilon-1}}$$

are calculated from the CES production function. Together with (6), these expressions would prove (8).

Comparative statics of equation (8):

$$w^* = \beta t(I)\left(\underbrace{\left(\theta^{\varepsilon}\omega(I;K)^{\varepsilon-1} + (1-\theta)^{\varepsilon}\right)^{\frac{1}{\varepsilon-1}} + \ \delta\left(\theta^{\varepsilon} + (1-\theta)^{\varepsilon}\omega(I;K)^{-(\varepsilon-1)}\right)^{\frac{1}{\varepsilon-1}}}_{\equiv\Omega(I;K)}\right).$$

First, with (7), differentiating $\Omega(I;K)$ with respect to I yields

$$\frac{\partial\Omega(I;K)}{\partial I} = \theta^{\varepsilon}\left(\theta^{\varepsilon} + (1-\theta)^{\varepsilon}\omega(I;K)^{-(\varepsilon-1)}\right)^{\frac{2-\varepsilon}{\varepsilon-1}}\ \Psi(I;K)\ \frac{d\omega(I;K)}{dI},$$

where

$$\Psi(I;K) \equiv 1 - \delta\left(\frac{L - \beta Z^* \int_0^I t(i)di}{K - \delta\beta Z^* \int_0^I t(i)di}\right)$$

and

$$\frac{d\omega(I;K)}{dI} = (\omega(I;K))^{1-\varepsilon} \left(\frac{1-\theta}{\theta}\right)^{\varepsilon} \frac{\beta Z^* t(I)}{\varepsilon} \frac{K-\delta L}{\left(L-\beta Z^* \int_0^I t(i)di\right)^2}.$$

Note that both $\Psi(I;K)$ and $d\omega(I;K)/dI$ are strictly positive if and only if $K > \delta L$. Thus, $\partial\Omega(I;K)/\partial I > 0$ always holds. Given $t'(I) > 0$, the right-hand side of (8) increases with I.

Next, differentiating Ω with respect to K yields

$$\frac{\partial\Omega\left(I;K\right)}{\partial K} = \theta^{\varepsilon}\left(\theta^{\varepsilon}\omega\left(I;K\right)^{\varepsilon-1} + (1-\theta)^{\varepsilon}\right)^{\frac{2-\varepsilon}{\varepsilon-1}} \omega\left(I;K\right)^{\varepsilon-2}\ \Psi\left(I;K\right)\ \frac{d\omega(I;K)}{dK},$$

where, in the same way as above, $\Psi\left(I;K\right) > 0$ if and only if $K > \delta L$. Given that $d\omega(I;K)/dK > 0$ always holds, we have shown that the right-hand side of (8) increases with K if $K > \delta L$ and decreases with K if $K < \delta L$.

Appendix B (for online publication only)

In this appendix, we explore the robustness of our result when the foreign variables are endogenously determined in a two-country setting. Once again, we assume that there are more factors than produced goods in order for the effects of factor supplies to work explicitly. Therefore, we can naturally consider the case of complete specialization. Suppose that the home country produces good y, whereas the foreign country produces good x. In this setting, we find that there is an additional relative-price effect that works against the capital-supply effect that we have identified above. On the one hand, the relative-price effect gives rise to a positive effect of capital on offshoring. On the other hand, the capital-supply effect gives rise to either a negative effect (when $\delta = 0$) or an inverted-U effect (when $\delta > 0$) of capital on offshoring. Suppose δ is equal to zero; in this case, capital has a monotonically negative (positive) effect on offshoring if and only if the elasticity of substitution between x and y is greater (less) than unity. Therefore, the model is unable to generate an inverted-U relationship between capital and offshoring under $\delta = 0$. However, under $\delta > 0$, capital has an inverted-U effect on offshoring if and only if the elasticity of substitution between x and y is greater than unity. For simplicity, we focus on the case of the Cobb-Douglas production function for the production of goods x and y.

We follow Grossman and Rossi-Hansberg (2008) by assuming that foreign firms use superior technologies. The technology difference implies that factor prices are higher in the foreign country than in the home country in equilibrium. Since all task trade is costly, only the firms in the country with superior technologies engage in offshoring. Let $A^* < 1$ denote the technological superiority of foreign firms. This implies that if a foreign firm does all tasks at the same level as a home firm, the output of the foreign firm is greater $1/A^*$ times.

The unit cost for foreign firms in industry j can be written as

$$A^* w^* a_{Lj}^* (1 - I) + A^* (w + \delta r) a_{Lj}^* \int_0^I \beta \ t(i) \ di + A^* r^* a_{Kj}^*. \tag{B1}$$

By using (1), the unit cost (B1) can be written as $A^* \left(w^* a_{Lj}^* \Omega(I) + r^* a_{Kj}^* \right)$, where $\Omega(I) = 1 - I + \int_0^I t(i) \ di \ /t(I)$. Perfect competition in the foreign country for industry x requires that

$$A^* \left(w^* a_{Lx}^* \Omega(I) + r^* a_{Kx}^* \right) = p_x. \tag{B2}$$

Perfect competition in the home country for industry y is characterized by (2).

The labor market clearing condition in the home country in (3a) and (3b) can be rewritten as

$$a_{Ly} \ y + \beta a_{Lx}^* x^* \int_0^I t(i) di = L \text{ and } a_{Ky} \ y + \delta \ \beta a_{Lx}^* x^* \int_0^I t(i) di = K, \tag{B3}$$

noting $Z^* = a_{Lx}^* x^*$. As for the foreign country, we can have

$$a_{Lx}^* x^* = \frac{L^*}{1 - I} \text{ and } a_{Kx}^* x^* = K^*. \tag{B4}$$

From (B3) and (B4), we express the capital intensities as

$$\frac{a_{Ky}}{a_{Ly}} = \frac{(1 - I)K - \delta \ \beta L^* \int_0^I t(i) di}{(1 - I)L - \beta L^* \int_0^I t(i) di} \text{ and } \frac{a_{Ky}^*}{a_{Ly}^*} = \frac{(1 - I) \ K^*}{L^*}. \tag{B5}$$

The good market equilibrium condition requires that the relative supply and demand are cleared in equilibrium:

$$\frac{x^*}{y} = D(p_x), \tag{B6}$$

where $D(p_x)$ denotes the world relative demand for good x with the usual property $D'(p_x) < 0$. We assume a CES utility function, so that the relative demand function becomes $D(p_x) = \left(\frac{\alpha}{1-\alpha}\frac{1}{p_x}\right)^\sigma$, where α is the share parameter for x and σ is the elasticity of substitution between x and y.

For simplicity, we consider the Cobb-Douglas technology in both countries: $(a_{Kx})^\theta (a_{Lx})^{1-\theta} = 1$ for the home country and $(a^*_{Kx})^\psi (a^*_{Lx})^{1-\psi} = 1$ for the foreign country, where ψ is a factor share of capital in the foreign country. Cost minimization gives rise to the factor price ratios as

$$\frac{w}{r} = \frac{1-\theta}{\theta}\left(\frac{a_{Ky}}{a_{Ly}}\right) = \frac{1-\theta}{\theta}\frac{(1-I)K - \delta\ \beta L^* \int_0^I t(i)di}{(1-I)L - \beta L^* \int_0^I t(i)di} \equiv \omega(I;K) \tag{B7}$$

and

$$\frac{w^*\Omega(I)}{r^*} = \frac{1-\psi}{\psi}\left(\frac{a^*_{Ky}}{a^*_{Ly}}\right) = \frac{1-\psi}{\psi}\frac{(1-I)\,K^*}{L^*} \equiv \omega^*(I), \tag{B8}$$

in which we apply (B5). Cost minimization also results in the unit factor demands as

$$a_{Ly} = \left(\frac{\theta\omega(I;K)}{1-\theta}\right)^{-\theta} \text{ and } a_{Ky} = \left(\frac{\theta\omega(I;K)}{1-\theta}\right)^{1-\theta} \tag{B9}$$

for the home country and

$$a^*_{Lx} = \left(\frac{\psi\omega^*(I)}{1-\psi}\right)^{-\psi} \text{ and } a^*_{Kx} = \left(\frac{\psi\omega^*(I)}{1-\psi}\right)^{1-\psi} \tag{B10}$$

for the foreign country.

Now we can characterize the equilibrium prices (p_x, w, r, w^*, r^*), by using the above conditions. By substituting (B3) and (B4) into (B6),

$$\frac{L^*}{(1-I)\,L - \beta L^* \int_0^I t(i)di}\frac{a_{Ly}}{a^*_{Lx}} = D(p_x) = \left(\frac{\alpha}{1-\alpha}\frac{1}{p_x}\right)^\sigma.$$

By substituting (B7), (B8), (B9) and (B10) into this, the relative price of good x is obtained as

$$p_x = \frac{\alpha}{1-\alpha}\left(\frac{(1-I)^{1-\psi}}{(K^*)^\psi (L^*)^{1-\psi}}\left(K - \delta\ \beta L^* \frac{\int_0^I t(i)di}{1-I}\right)^\theta \left(L - \beta L^* \frac{\int_0^I t(i)di}{1-I}\right)^{1-\theta}\right)^{\frac{1}{\sigma}} \equiv p(I;K), \tag{B11}$$

where $dp(I;K)/dI < 0$ and $dp(I;K)/dK > 0$. By (2), (B7) and (B9), we obtain the factor prices in the home country as

$$w = \tilde{\theta}\ \omega(I;K)^\theta \equiv w(I;K) \text{ and } r = \tilde{\theta}\ \omega(I;K)^{-(1-\theta)} \equiv r(I;K). \tag{B12}$$

where $\tilde{\theta} \equiv \theta^{\theta} (1-\theta)^{1-\theta}$. By (B2), (B8), and (B10), we obtain the foreign wage as

$$w^* = \frac{1-\psi}{A^*} \left(\frac{K^*}{L^*}\right)^{\psi} \frac{\overbrace{p(I;K)}^{\text{Relative price effect}} \cdot \overbrace{(1-I)^{\psi}}^{\text{Labor supply effect}}}{\underbrace{\Omega(I)}_{\text{Productivity effect}}} \equiv w^*(I).^{15} \tag{B13}$$

As in Grossman and Rossi-Hansberg (2008), we can decompose the wage effects of offshoring in the offshoring country into the productivity effect, the relative price effect, and the labor supply effect.

By (B12) and (B13), the offshoring condition (1) can be expressed as

$$\underbrace{\tfrac{1-\psi}{A^*\Omega(I)} \left(\tfrac{(1-I)K^*}{L^*}\right)^{\psi} \quad p(I;K)}_{w^*(I)} = \beta t(I) \left(\underbrace{\tilde{\theta}\omega(I;K)^{\theta}}_{w(I;K)} + \delta \underbrace{\tilde{\theta}\ \omega(I;K)^{-(1-\theta)}}_{r(I;K)}\right), \tag{B14}$$

which is identical to (8) except that the foreign wage is endogenous as a function in I and K. Using (B14), we can show that Proposition 1 is robust in the two-country setting. Define $\phi \equiv 1 - \frac{1}{\sigma}$ for simplicity. Then we have:

Proposition 2 *Suppose that $\sigma > 1$ and $\delta > 0$. As capital K increases in the offshored country, the equilibrium level of offshoring I first increases and then decreases. There is an inverted U-shaped relationship between K and I.*

Proof. Note that when $\sigma > 1$, $\phi \in (0,1)$. By using (B7) and (B11), (B14) can be rewritten as

$$\begin{aligned} & \frac{\alpha(1-\psi)(K^*)^{\psi\phi}}{(1-\alpha)\beta A^* (L^*)^{\psi\phi+(1-\phi)}} \frac{(1-I)^{\psi\phi+(1-\phi)}}{t(I)\Omega(I)} \\ = \ & (1-\theta)\left(K - \delta\beta L^* \frac{\int_0^I t(i)di}{1-I}\right)^{\theta\phi} \left(L - \beta L^* \frac{\int_0^I t(i)di}{1-I}\right)^{-(1-(1-\theta)\phi)} \\ & + \delta\theta \left(K - \delta\ \beta L^* \frac{\int_0^I t(i)di}{1-I}\right)^{-(1-\theta\phi)} \left(L - \beta L^* \frac{\int_0^I t(i)di}{1-I}\right)^{(1-\theta)\phi}. \end{aligned} \tag{B15}$$

We can easily show that the left-hand side (LHS) of (B15) decreases with I (noting that $t(I)\Omega(I)$ increases with I due to the definition of $\Omega(I)$). We can also show that the right-hand side (RHS) of (B15) increases with I by differentiating it with respect to I with $\phi < 1$. With (P1) and (P2), (B15) uniquely determines the equilibrium level of I, as an intersection of both sides, denoted as $I(K)$.

[15] Note: $r^* = \frac{\psi}{A^*} p_x \left(\frac{L^*}{(1-I)K^*}\right)^{1-\psi}$.

By differentiating the RHS of (B15) with respect to K given I, we can show that the RHS decreases (increases) with K if

$$K < (>) \ \delta \frac{1-\theta\phi}{(1-\theta)\,\phi}\left(L - \frac{1-\phi}{1-\theta\phi}\beta L^* \frac{\int_0^{I(K)} t(i)di}{1-I(K)}\right) \equiv \Phi(K). \tag{B16}$$

In completing the proof, we first consider the lower bound of K, i.e., $\delta\beta L^* \int_0^I t(i)di/(1-I)$,[16] around which $K < \Phi(K)$ holds.[17] Given that the RHS (LHS) of (B15) is upward (downward) sloping in I, this implies that $dI(K)/K > 0$ for lower K.

Then, when K increases from the lower bound, $I(K)$ increases and thus, by (B16), $\Phi(K)$ decreases. Thus, as K increases, $K < \Phi(K)$ will eventually become $K = \Phi(K)$. Define $\hat{K}$ by $\hat{K} = \Phi(\hat{K})$; then, $dI(\hat{K})/dK = 0$ holds. When K marginally increases from $\hat{K}$, the marginal increase of the LHS in (B16) is 1, whereas that of the RHS is 0 (since $dI(\hat{K})/dK = 0$ and $d\Phi(\hat{K})/dK = 0$). Therefore, there exists $\varphi > 0$ such that for $K \in (\hat{K}, \hat{K}+\varphi)$, $K > \Phi(K)$ and thus $dI(K)/dK < 0$.

Finally, when K further increases, $I(K)$ decreases (since $dI(K)/dK < 0$), and so $\Phi(K)$ increases. Thus, as K continues to increase from $\hat{K}$, $K < \Phi(K)$ may hold again. However, we can show that this is not the case. Suppose there exists $\tilde{K} > \hat{K}$ such that $\tilde{K} = \Phi(\tilde{K})$. This requires $dI(\tilde{K})/dK = 0$ and thus $d\Phi(\tilde{K})/dK = 0$, so that a further increase in K from $\tilde{K}$ leads to $K > \Phi(K)$ for the same reason as above. Therefore, $K \geq \Phi(K)$ holds for any $K > \hat{K}$. Given that $K > \Phi(K)$ holds for a sufficiently large K (since $\Phi(K)$ is bounded from above), it implies $K > \Phi(K)$ holds for any $K > \hat{K}$. Then, we have $dI(K)/dK < 0$ for $K > \hat{K}$, proving an inverted-U relationship between K and I. ■

[16] The lower bound comes from the assumption that $K > \delta\beta L^* \int_0^I t(i)di/(1-I)$.

[17] Note that $0 < \phi < 1$ and the assumption $L - \beta L^* \int_0^I t(i)di/(1-I) > 0$. Also note that $\Phi > 0$ since $(1-\phi)/(1-\theta\phi) \in (0,1)$ by $\phi \in (0,1)$.